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ARTIFICIAL RECHARGE FOR SUSTAINABLE GROUNDWATER MANAGEMENT PLAN IN YOGYAKARTA

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ABSTRACT

Aim: This study investigates the development of a sustainable groundwater management strategy in Yogyakarta province through groundwater recharge technologies. This study also compares technologies used in the province and the one already implemented in Perth due to its similar nature in site geology and hydrogeology. **Methodology and Results:** Primary and secondary data were collected and analyzed. Water depth and hydraulic conductivity data were analyzed using permeameter and GIS program. GIS image analysis of water depth and hydraulic conductivity suggested that the placement of potential aquifer recharge sites would be best suited in the north - east part of the province, slightly outside the study area, to provide water for all. Two recharge schemes of an infiltration basin and an injection well with storm water detention tank were proposed. The injection well was decided upon, despite its higher cost, due to the impermeability of soils in Yogyakarta and possible water seepage to the environment. Similar to Perth's Hartfield park scheme, an injection well would directly bypass these soil layers to recharge the aquifers with rainwater and storm water. Hartfield Park injects 4,400 kL of water/year. **Conclusion, significance and impact study:** The findings of this study indicate aquifer recharge is a possible solution to overcome Yogyakarta's high abstraction. Further studies recommend that injection well trials are further developed in terms of location, depth and sizing.

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1. INTRODUCTION

Shallow groundwater aquifers are water resources commonly used in some cities around the world, especially in places where they directly underlys sandy and/or loam soil, as seen in Yogyakarta, Indonesia and Perth, Australia. Therefore, aquifers are highly vulnerable to contamination from urban and agricultural activities, sea water intrusion (Appleyard, 1995; Putra, 2007) as well as abstraction beyond sustainable yield.

The several researches conducted on the groundwater in Yogyakarta have not achieved a relevant water management strategy to tackle the deteriorating condition. This research is also concerned with comparing the state of groundwater in Perth whose population is expected to reach 3.5 million in 2050 with Yogyakarta. While several government agencies and environmental groups continue to raise awareness on policies and the issue of water scarcity, contamination and over - abstraction keeps rising in the city and its surrounding suburbs. Some studies have found that a decline in rainfall, extensive land use and excavation have led to widespread contamination.

This study is focused on the sustainable management of groundwater for the future. The core of this research was targeted on Yogyakarta and how best to encourage sound aquifers across all regions, using computational models such as GIS (i.e. ArcGIS and Terrset). The input of storm water into groundwater was also discussed, for a better management of severe storm events. Policy amendment and government assistance can improve behavioral patterns of residents and further maintain groundwater for a long - term period. The findings of this research were also compared with current practices in Perth to assess if the proposed solutions will be viable. This study served as the first step in the development of an enduring strategy to provide secure water to the residents of Yogyakarta Province in the future. It will also have an insight into using tactics currently being applied in Perth, owing to the similarity of both cities.

2. RESEARCH METHODOLOGY

2.1 Water Depth and Hydraulic Conductivity

The sampling sites were within the study area. These locations were predetermined based on their frequency of use by local residents and that they include all five regencies in the project regime. Most of the locations were concentrated within the urban center and the Regency of Sleman, this is where a vast urban population dwells and groundwater extraction is at its peak.

However, southern and western regions (Bantul and Kulon Progo) were included in the study to assess the impact of groundwater recharge and pollution in coastal areas. Groundwater extraction sites were usually private or connected to the PDAM (Perusahaan Daerah Air Minum – private Indonesian water company) – others were public wells. Figure 1 shows the different location across the eighteen provinces sampled for this study.

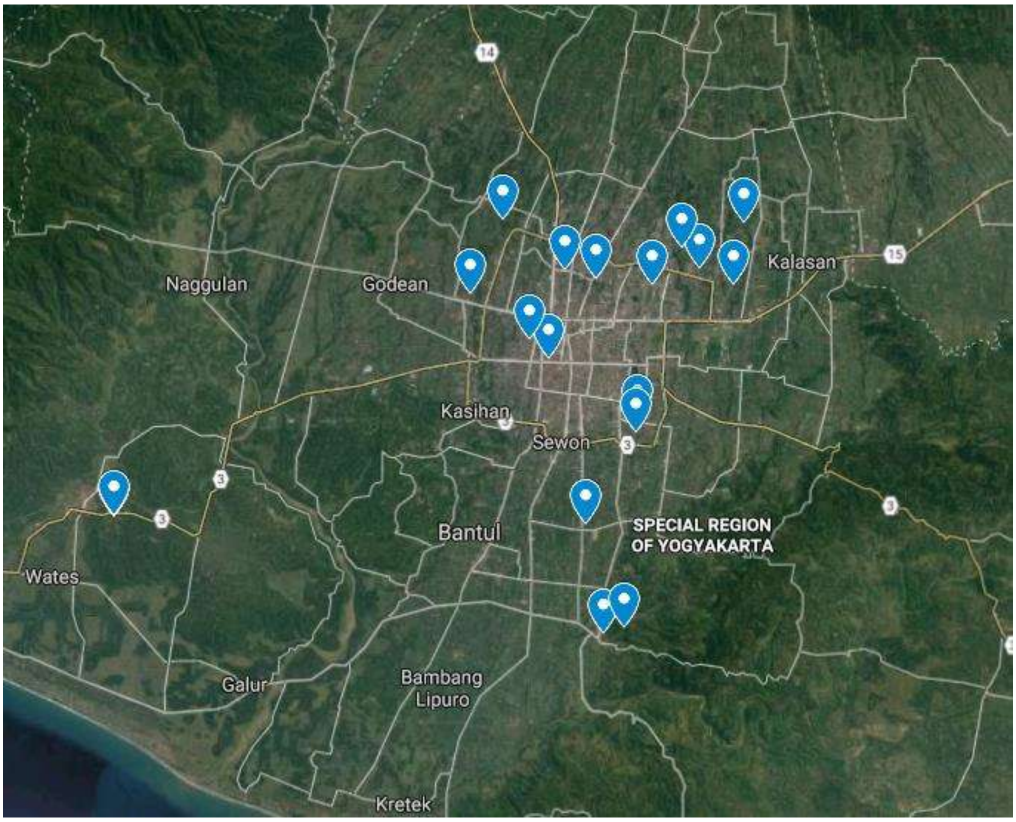

Figure 1 Sampling points in study area

The water table was measured using a water sensor which was attached to the base of a cylindrical instrument, developed to test the hydraulic head at the site. This is slowly lowered using a measuring tape and when the sensor detects water, the measurement from the tape is taken. In some locations where the outer wall of the bore disturbs ground - to - water readings, the height of the well lips was taken as well. This was therefore subtracted from the value measured down to obtain the length of the hydraulic head from the ground.

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A permeameter was used to measure the hydraulic conductivity, modelled after the Talsma-Hallem method of measuring Ksat. After using an auger to dig a shallow hole, the soil was then wetted with water. The permeameter was further placed on top of this area. Water rises back up the instrument through the inner tube. This technique works by maintaining a constant head pressure in the groundwater level. Computing water depth and hydraulic conductivity, ArcGIS and Terrset software were then used to create models that would determine which areas would be most suitable for a recharge.

2.2 Ground Water Recharge

Groundwater recharge means to replenish underground aquifers with inputs of water which ranges from freshwater sources such as rain to industrial waste liquids and sewerage (raw or treated). There are several ways total groundwater recharge can be calculated. A study in Yogyakarta used equation 1, as follows:

$$G_{wi} = (P - E)\, x\, I + \Delta s \tag{1}$$

Where, Gwi = Groundwater Recharge; P = Precipitation; E = Evapotranspiration, I = Infiltration Rate; Δs = Change in Groundwater Storage

This can also be categorically summarized by Equation 2. This formula is universally used for predicating groundwater recharge, thus, this can be used for the groundwater in Perth as well.

$$U = P - E_{Tr} - R_O \tag{2}$$

where U = Groundwater Recharge (mm/year) P = Precipitation (mm/year); E_{Tr} = Evapotranspiration (mm/year) Ro = surface runoff (mm/year).

2.2.1 Urban Recharge

Total urban recharge includes leaks, sewage and industrial effluent (Manny, *et al*, 2011). This is shown in Equation 3, as follows.

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$$UU = LI + LS + LW + Lnd \tag{3}$$

where UU = Total Urban Recharge LI = Leakage from Water Supply System LS = Leakage from Sewer System LW = Non - Exported Domestic Waste Water and Lnd = Non - Domestic Wastewater. Table 1 below illustrates the breakdown of urban groundwater recharge in Yogyakarta.

Table 1 Table of urban recharge parameters in Yogyakarta

No	Component of Urban Rechange	Q (million m^3/a)
1.	[a]Total domestic use (Q_D); about 70% demand is fulfilled by local shallow groundwater abstraction and less than 30% of demand can be supplied from the existing water supply system	51.17
2.	[a]Domestic consumptive use (Q_c)	6.92
3.	Potential Domestic waste water ($W_p = Q_D – Q_c$)	44.25
4.	[a]Domestic waste water exported via existing sewer system (W_s)	2.56
5.	Domestic waste water not exported ($W_{NE} = W_p – W_s$)	41.69
6.	[b]Leakage from water supply system (L_I)	5.76
7.	[a]Leakage from sewer system (L_s)	0.37
8.	[a]90% not exported domestic waste water (L_w = 09. X W_{NE})	37.5
9.	[c,d]90% non-domestic wastewater (L_{nd})	1.95
10.	Net urban groundwater recharge ($U_u = L_I + L_s + L_w + L_{nd}$)	45.6

2.2.2 Artificial Aquifer Recharge by Storm water

The injection of treated water into groundwater reserves, either forced or passively, increases the quantity of water, hence the longevity of an aquifer can be obtained. They however do not require complex water treatment, which makes them ideal for medium sized communities. A study in the Netherlands found that recharge schemes are much more economically viable when compared with water treatment plants in developing countries. Yogyakarta contains semi - confined aquifers, which is a challenge as direct infiltration cannot occur. Several technical factors must be taken into account to assess the viability of an artificial recharge schemes, these include retention time, permeability, storage capacity, infiltration rate porosity.

Infiltration rate (Qi) is calculated using the formula as follows:

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$$Q_i = A \, . K_{sat} \quad (4)$$

where :

Ksat = saturated hydraulic conductivity (m/s)

A = area of infiltration (m2)

There are several ways of recharging an aquifer as those in Yogyakarta are unconfined in nature. Focus will therefore be geared towards infiltration basins and induced recharge.
Depth of infiltration basin was determined using Equation 5:

$$d = f_d \, . t_{max} \quad (5)$$

where:

d = Depth of infiltration basin (m)

fd = Design Infiltration Rate (m/hr)

t_{max} = Detention time (hr)

Due to water stress, Perth has developed several artificial recharge schemes to replenish groundwater resources. The sand, gravel and limestone composition in its slow sand filtrating soil is likened to artificial aquifer recharge systems hence, infiltration galleries are popular. However, they get clogged much more easily - an infiltration gallery in Floreat, Perth experienced excessive clogging due to the high concentration of sediments.

Hartfield Park, in the city of Kalamunda, injected filtered storm water into the Leederville aquifer. Between June and October 2016, the injection captured and successfully stored 4,400 kiloliters into the Leederville. Another scheme involves using treated wastewater from residences to replenish groundwater aquifer – this is located at the Beenyup water replenishment site, which is projected to constitute at least 20% of Perth's drinking water supply by 2060.

3. RESULTS AND DISCUSSION

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3.1 Water Depth and Hydraulic Conductivity

Figure 2 shows the different locations exploited in Yogyakarta and their corresponding depths. The purple points on the map represent the site locations. Using ArcGIS, a raster interpolation was conducted to gain an understanding of water depth for the entire study area, despite not having more sample points. Sites that feature warmer colors (i.e. red, orange, yellow), were observed to have significantly low water tables, ranging from 9.31 - 18 meters. Conversely, areas in cooler tones (blue and green) have much higher hydraulic heads. This means that low water depth is concentrated in the north - east of the study area.

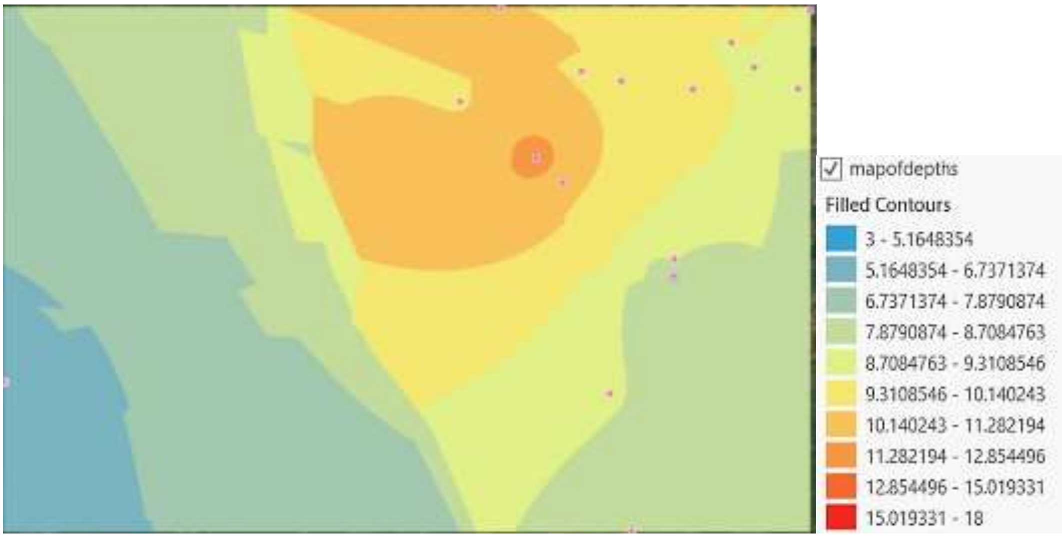

Figure 2 Map of water depth (m)

Figure 3 is a representation of hydraulic conductivity within the study area. Similar to the previous illustrations of water depth, the raster interpolation tool from ArcGIS provided image analysis for the whole study area, allowing generalizations to be made. Warmer colors are indicative of high hydraulic conductivity zones while cooler tones are noted for zones with lower hydraulic conductivity as represented by the scale to the right of Figure 3. From the image, it is observed that hydraulic conductivity increased to the eastern end of the study area.

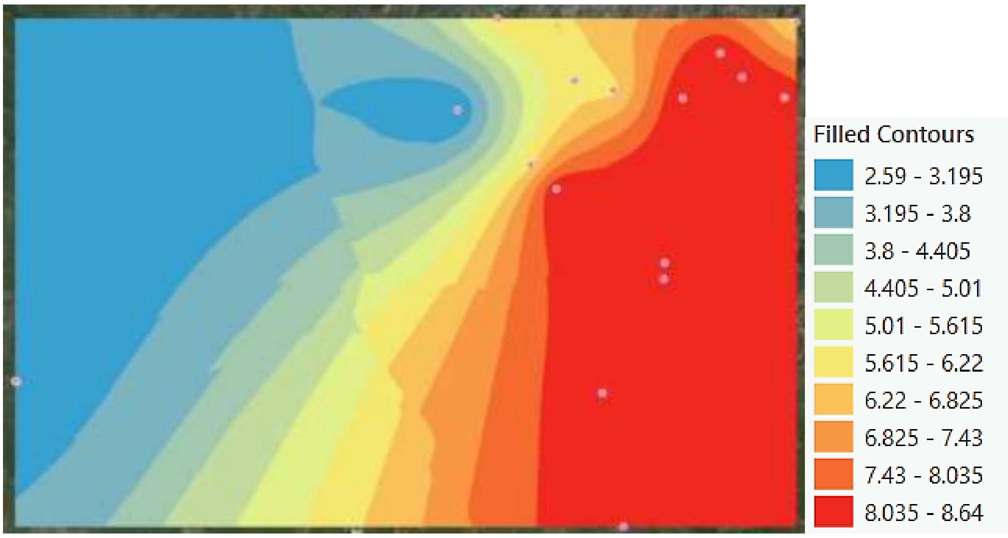

Figure 3 Hydraulic conductivity (m/day)

3.2 Artificial Aquifer Recharge

3.2.1 Site Suitability for proposed Recharge Location(s)

To evaluate if artificial aquifer recharge was suitable in Yogyakarta, variables such as slope, land cover, water depth and hydraulic conductivity were assessed. Contour maps and GIS images were created for the variables which were then collectively analyzed to determine the best locations for the proposed artificial recharge project. Soil geological GIS image was not created because surface geology was consistent throughout the study area.

Areas where groundwater depth is critical are concentrated in the northern part of Yogyakarta. However, due to the north - to - south trajectory of groundwater in the region, fixing it in this location implied that the water table would increase down south of the target zone, this provides no relief in these areas despite their proximity to the recharge site. It was therefore proposed that aquifer recharge lie further north, slightly outside the bounds of the study area. This was based on the reasons, explained below:

1. By placing the recharge location further north of the study area, it will ensure that the groundwater table increases in all regions.
2. The placement in less populated areas outside the urban city would decrease chances of any urban obstruction for example, walking on the infiltration zone.

It was observed that the main areas where groundwater depth is severe are in opposing zones – one has a much higher hydraulic conductivity as compared to the other. Placement of aquifer design is based on hydraulic conductivity - a passive infiltration basin would favor the north-eastern region of Yogyakarta, where hydraulic conductivity is high. To compare the effect this would have on infiltration, Table 2 and Figure 4 was produced using equation (4).

Table 2 Effect hydraulic conductivities on infiltration rate

Hydraulic Conductivity (m/day)	Q for Infiltration Basin (m^3/s)
Low conductivity (5.16 m/day)	1.1574
High Conductivity (8.64 m/day)	1.9907

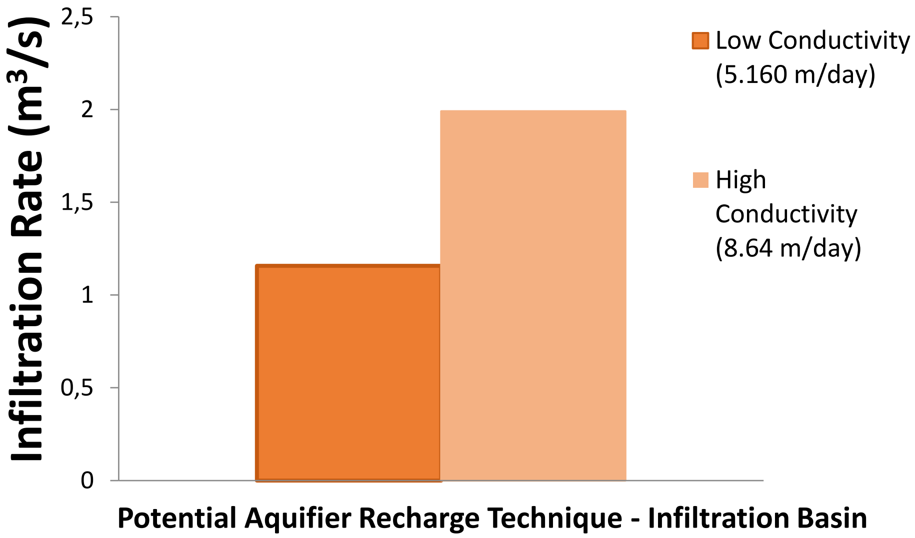

Figure 4 Infiltration rate (Q) vs hydraulic conductivity (K)

Placing the artificial aquifer recharge systems in a location with higher hydraulic conductivity improves infiltration by almost 42%. As such, instead of focusing on the northern boundary of the city for capture, the target area became narrowed to the north-eastern edges of the city for maximum retention of rainwater and storm water. A four-kilometer buffer zone was also applied around the sites so the recharge zone would be located outside of the City - this was determined by estimating radial distance around the city center in the northern areas.

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This was to ensure that urban obstruction to the recharge zone, and in turn any disruption caused by the development, would be minimal.

3.2.2 Recharge Options

In strategizing a recharge option, two different types of aquifers - unconfined and confined were analyzed. There was a proposed design for each option as shown by Figure 5 and 6 below. The minimum recommended area for the infiltration basin is two hectares and the proposed area in Figure 5 was chosen and its depth was determined using Equation 5.

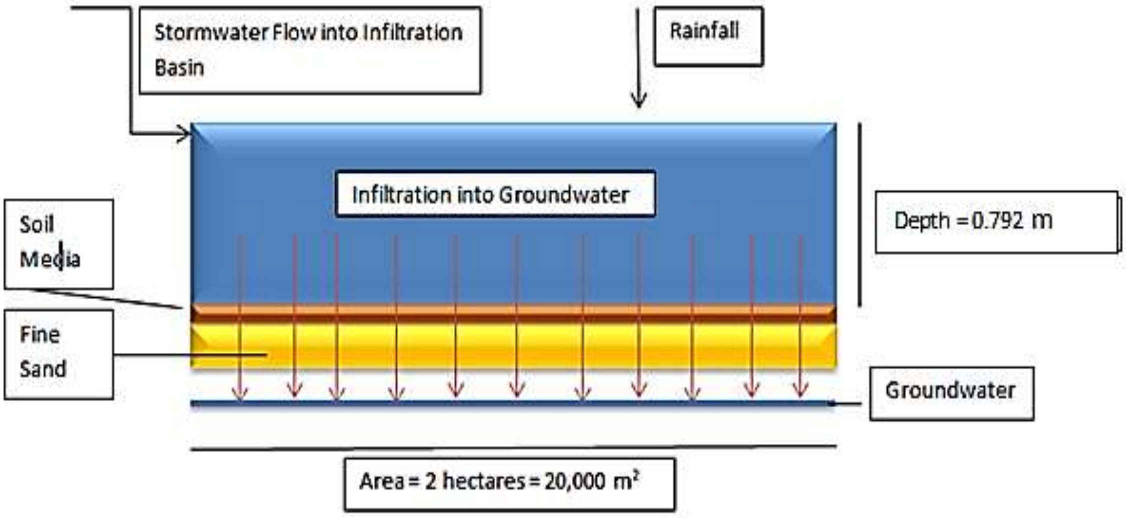

Figure 5 Schematic of infiltration basin

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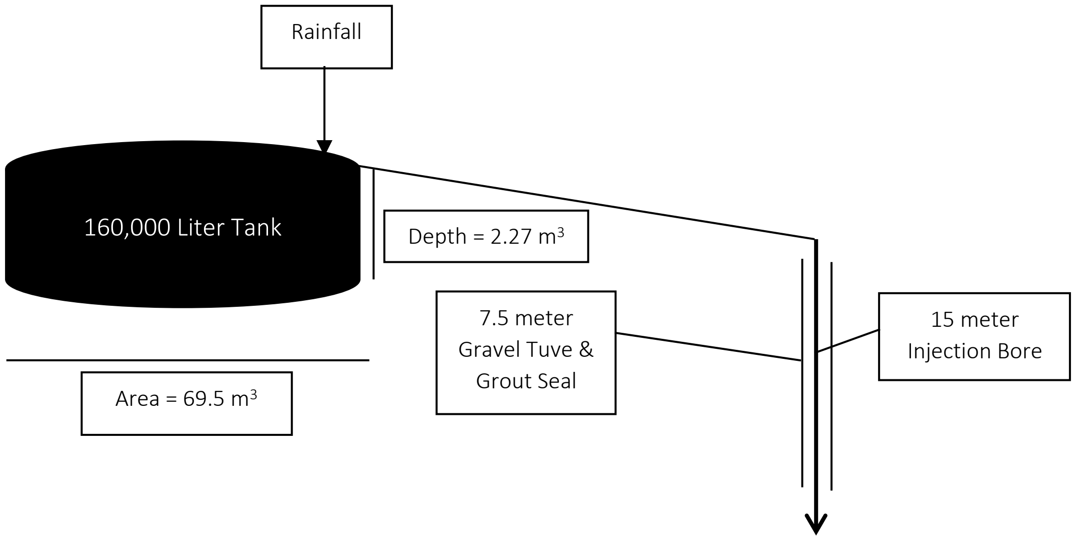

Figure 6 Schematic of proposed water detention and injection

Storm water and rainwater serves as inputs, with the only output being through the basin itself, via the porous media, into the groundwater. Alternatively, in Figure 6, rainwater is received into an above - ground surface water tank, which is preferable to be at a higher elevation than the bore - the Yogyakarta Province is on a slope. Therefore, a suitable location north of the injection well can be found from which it is pumped to a bore where it is injected into aquifer below. There are merits to both systems, as discussed in Table 3 below.

Table 3 Comparison of infiltration basins versus injection wells

Factors to Consider	Infiltration Basin	Injection Well
Capital Cost	$ 8,333/acre = $ 16,666 for 6 hectare basin [75]	±$ 31,000 including bore digging, storage tank, pump cost & installation, gravel tube, grout seal
Maintenance	Self maintenance Potential problem: clogging by suspended matter & silts	High cost maintenance Potential problem: – Clogging – Lack of capable operator can lead to errors
Effectiveness in recharging aquifer	Slow, dependent on storm water inflow and precipitation	Good, by passes soil/rock formations underground for direction injection
Rate of recharge	Slow	Fast
Placement location	open space	Open space

Infiltration basins were observed to be the preferred option; firstly, due to the high volume of water they are capable of holding. Although infiltration rate is slower when compared to injection wells, it has the merits of lower capital cost and relative self - maintenance. It also facilitates storm water diversion and management. This gives room for the development of a suitable strategy which Yogyakarta and Indonesia extensively lacks.

3.2.3 Contrast to Perth and Wider Australia

Similar recharge strategies are being used currently in Perth, such as the Development of Hartfield Park in Kalamunda. This extracts storm water from the Woodlupine Main Drain during winter, which recorded the injection of 4,400 kiloliters in 2016. Its utility is acutely similar to Yogyakarta - preservation of the welfare and future water security. As explained in the literature review, similar climate and geological conditions prove that the system will be technically viable in Yogyakarta. However, government must give permission and support before such a project is undertaken. In Perth, Water Corporations fully support groundwater replenishment, with the aptly named Groundwater Replenishment Scheme in Beenyup who restore the aquifers with highly treated wastewater. The government in Yogyakarta must have the same driving encouragement to facilitate the implementation of the proposed aquifer recharge strategy. Its potential success paves a path to forming more storm water management policies in cities across Indonesia, particularly in areas such as Yogyakarta where flash flooding commonly occurs.

4. CONCLUSION

In understanding the suitability for groundwater recharge, GIS images were created to understand the terrestrial overlay of the study area and interpolate water depth and hydraulic conductivity points. The result portray, the north - eastern sector of the study area would be best suited for recharge due to high hydraulic conductivity and proximity to areas that are most affected by decreasing groundwater levels. Four kilometers of buffer zones of radius were created around the north - eastern sites to determine the optimum location away from the confines of an urban setting. Recharge technologies were assessed by several values including cost, rate of recharge and maintenance. It was determined that an injection well via storm water capture tanks would serve best in this area, primarily due to low cost and high capture without loss of water to absorption by soil. This technology is currently being applied in Perth on a large scale at Hartfield Park in Kalamunda and the Andrews' Farm in South Australia, with both yielding positive results, verifying the operation of this proposed development.

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